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ABSTRACT

Vertical wind components were computed up to 1.2 km from 37 wintertime and 10 summertime balloon observations between 0900 and 1200 local time utilizing the accurate and high resolution Cinetheodolite/Jimsphere system. The mean ascent rate of the Jimsphere was computed from all observations taken on a particular day. The ascent rate was found to be 5.16 m sec^{-1} for the winter and 5.10 m sec^{-1} for the summer months. The individual variations of a given observation from the mean ascent rate were assumed to be the vertical component. Variations in balloon ascent caused by variation in drag, anomalous variation in atmospheric density, balloon response to the wind, and aerodynamically induced motions are discussed. Vertical wind components ranged from 10 - 25 cm sec^{-1} in a stable atmosphere and 55 - 100 cm sec^{-1} under unstable conditions depending on wind speed.

ACKNOWLEDGEMENT

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CONTENTS

INTRODUCTION

Considerable attention has been given to the vertical component of atmospheric turbulence in the very lowest few meters of the atmosphere, but far too little study has been made of the fluctuations of the vertical wind component above meteorological tower level. There are two reasons for this; first, the parameters are most accessible to measurements at tower heights; and second, a convenient organization of the data has developed gradually from the standpoint that the turbulent properties are characterized by the vertical fluxes of momentum and heat, both of which are assumed constant within the lowest few meters of the atmosphere. As a result, there are available useful, although empirical, generalizations (Lumley and Panofsky, 1964) from which certain statistical properties of turbulence are prescribable, given a knowledge of the terrain and general weather conditions. At greater heights, above about 100 m, conditions are very different, and the acquisition of acceptable quality data is much more difficult. Moreover, the simplifications of constant stress and flux are not applicable. The understanding of the mechanics of turbulent motion presents a much more difficult task above the surface boundary layer. Nevertheless, the deeper layer is of considerable importance in meteorological problems, especially in the sense that its properties determine the medium-range spread of atmospheric contaminants.

Until recently, there have been only two main sources of direct measurement of vertical wind components at heights above tower level. The two techniques have been primarily measurements from vanes on tethered balloons (Smith, 1961) and the use of a slow aircraft for a platform (Bunker, 1956). Recently, DeMandel and Krivo (1968) investigated the capability of the FPS-16 Radar/Jimsphere system for direct measurement of vertical air motions up to an altitude of 15 km. They concluded that a measure of the vertical wind component may be derived from Jimsphere (a 2 m diameter superpressure balloon of constant volume) ascent-rate data despite the high noise level in the original data and despite the difficulty in distinguishing between balloon response to bouyancy and to vertical air motions.

Most of the data in this study were obtained utilizing 2 m diameter Jimspheres, except on 10 July 1967 when one-meter diameter Jimspheres were used. Some important techniques used in this study that differ from those used by DeMandel and Krivo are: (1) the tracking of the Jimsphere balloon was accomplished by accurate and high-resolution cinetheodolite cameras (three or four) instead of the FPS-16 radar, which, according to Scoggins and Armendariz (1969) contains many sources of errors, and (2) the data extended to an altitude of only 1.2 km as compared to 15 km in the DeMandel and Krivo study. In addition, there were some differences in the treatment of the data, but the objectives were basically the same. For example, the data in this paper were

smoothed by a least-squares 11-point moving-arc filter, whereas DeMandel and Krivo fitted a first-degree polynomial by the least-squares method as done by Scoggins (1963). Smoothing techniques virtually eliminated high frequency (>.22cps) aerodynamically induced balloon motions from the data as well as systems error. It will be shown that variations in the ascent rate of a constant volume balloon such as the Jimsphere due to density anomalies encountered during a particular flight up to 2 km are insignificant.

One of the primary applications of the results of this kind of vertical wind measurements is in the area of particle diffusion, particularly on a mesoscale under conditions of a thermally stratified atmosphere. The existence or lack of vertical current through a surface temperature inversion to stronger horizontal winds above can determine the rate of diffusion of contaminants released near the surface.

COLLECTION AND TREATMENT OF DATA

The data in this study were obtained from a number of Jimsphere balloons which were tracked by three or four cinetheodolite cameras on two wintertime days, 29 November 1966, and 12 December 1966, and two summertime days, 10 July 1967 and 5 August 1968.

Cinetheodolite position measurements in spherical coordinates were recorded at one-second intervals and were smoothed by an 11-point moving-arc second-degree polynomial (see Appendix) converted to cartesian coordinates; then x,y,z component velocities of the balloon movement were computed.

The mean z-component of the balloon movement was calculated for each run (made at 6-minute intervals), and an average of the means for all runs during a period of operation was assumed to be the mean ascent rate of the balloon for that particular period. For example, on the 29th of November 1966, the mean ascent rate was 5.16 m second^{-1} for all of the 2-meter Jimspheres released in a two-and-one-quarter-hour period. An identical ascent rate was obtained for all ascents during a two-hour period on the 12th of December 1966. The same procedure was followed with a series of 1-meter Jimspheres released on the 10th of July 1967, and the mean ascent rate was 4.23 m second^{-1}. On the 5th of August 1968, 2-meter Jimspheres were used, and the mean ascent rate was found to be 5.10 m second^{-1}.

The mean ascent rate for all Jimsphere runs conducted during an approximate two-hour period on a specific day (such as 29 November 1966, 5.16 m second^{-1}) was then subtracted from individual ascent rate profiles at each second data point and the differences assumed to be largely due to the effects of vertical air motions.

These differences, which will be called vertical wind (w), are considered to be downward if negative (less than the mean for the series on that particular day) and upward if positive (greater than the mean). These differences were algebraically averaged through 100 m layers from the surface to 1.2 km, yielding a net mean upward or downward wind component for each 100 m layer in the algebraic averaged results, or in the case where the sign (up or down) was disregarded, an absolute magnitude of the vertical components was obtained for each 100 m layer.

DISCUSSION AND RESULTS

Before one assumes that the variations in ascent rate in individual runs from the mean ascent rate for numerous runs taken during a two-hour period are due to vertical winds alone, one should consider known factors which may influence balloon motion. These include: (1) aerodynamically induced balloon motions, (2) balloon response to vertical shear of the horizontal wind, (3) icing and condensation, (4) variations in size and/or mass of the balloon, (5) anomalous variation in atmospheric density, and (6) variation in the drag coefficient.

The Jimsphere experiences aerodynamically induced oscillations having a wavelength of approximately 22 meters (Cf. Rogers and Camnitz, 1965; Armendariz and Rachele, 1967; and Rider and Armendariz, 1968). Most of these oscillations were removed by the smoothing technique used in this study (see Appendix). Extreme wind shears which are necessary to produce a significant change in the vertical motion of a Jimsphere must occur over a very thin layer and therefore their effect would be removed by the smoothing performed on the data (DeMandel and Krivo, 1968).

The data used in this study were obtained on days when the moisture content was far below saturation at the levels considered, and there was no precipitation in the vicinity at the time of balloon ascent.

The Jimsphere balloon is a constant-volume balloon, and it can be safely assumed within the limits of the data used, up to 1.2 km, that there was no significant change in the size or mass of the balloon and its helium content.

DeMandel and Krivo (1968) developed an expression for balloon ascent (V_z) by considering the forces on a balloon rising through a quiescent atmosphere. The resultant expression in CGS units can be written as:

$$C_D V_z^2 = 2.26\text{X}10^5 - \frac{1}{\rho}\left(25.5 + \frac{63.1}{T_b}\right) + 3.61\text{X}10^4 \frac{t}{T_b} \qquad (1)$$

where

C_D = coefficient of drag

V_z = balloon ascent rate

ρ = density

T_b = internal temperature of the helium

T = ambient temperature

t = deviation of temperature so that $T_b = T + t$.

[Since in this study T_b varied from approximately 250 to near 300°K, ρ varied from approximately 1.07×10^{-3} to $.92 \times 10^{-3}$ g cm^{-3}, and t was generally less than 10°K, the above expression was simplified to:

$$C_D V_z^2 = 2.26 \times 10^5 - \frac{1}{\rho} (25.5) \tag{2}$$

because the two terms dropped from equation (1) are approximately two orders of magnitude smaller than the others, as found by DeMandel et al.] Graphical presentation (Figure 10) of the change in C_D for a change in vertical wind speed for the limiting values of density in this study shows that for a given C_D, V_z can change approximately 5 cm second^{-1} due to the extreme change in density shown. However, it is improbable that such an extreme change of density would be encountered in the general atmosphere over small distances (less than 50 m), and one must conclude that anomalous variations in atmospheric density, within the time limits of this study, will cause only minor changes in ascent rate which can be safely disregarded.

If one considers the effect of wind shears or change in drag, DeMandel et al. found that, for the Jimsphere, extreme wind shears would change the vertical velocity of the balloon by no more than 1.5 cm second^{-1}. Moreover, they stated that a wind shear that would produce such a change in V_z would extend over a small vertical distance and that filtering or smoothing would remove this effect. The coefficient of drag (C_D) was found to be almost constant, approximately 0.760 at WSMR through the first 1.2 km above the surface. This value of C_D compares favorably with that of DeMandel et al., who found the C_D to be 0.730 for observations at Cape Kennedy.

Two examples of the magnitude and variation of the vertical component of the balloon motion are shown in Figures 1A and 1B. Variation of the ascent rate of the balloon released at 0945 MST, 29 November 1966, is shown in Figure 1A where the vertical solid line represents the mean

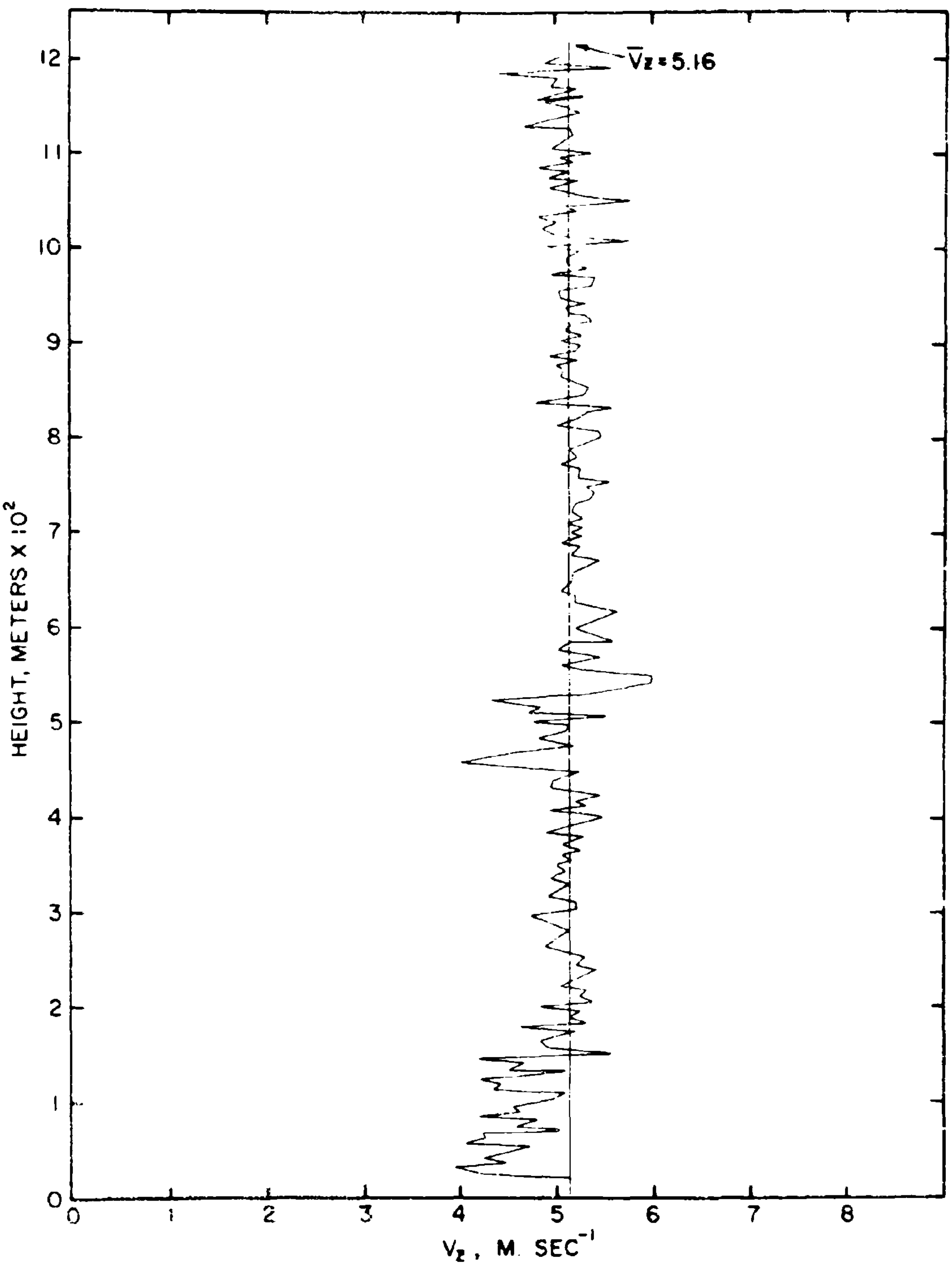

FIG. 1A. VARIATION OF THE ASCENT RATE OF THE JIMSPHERE BALLOON RELEASED AT 0945 MST 29NOV1966

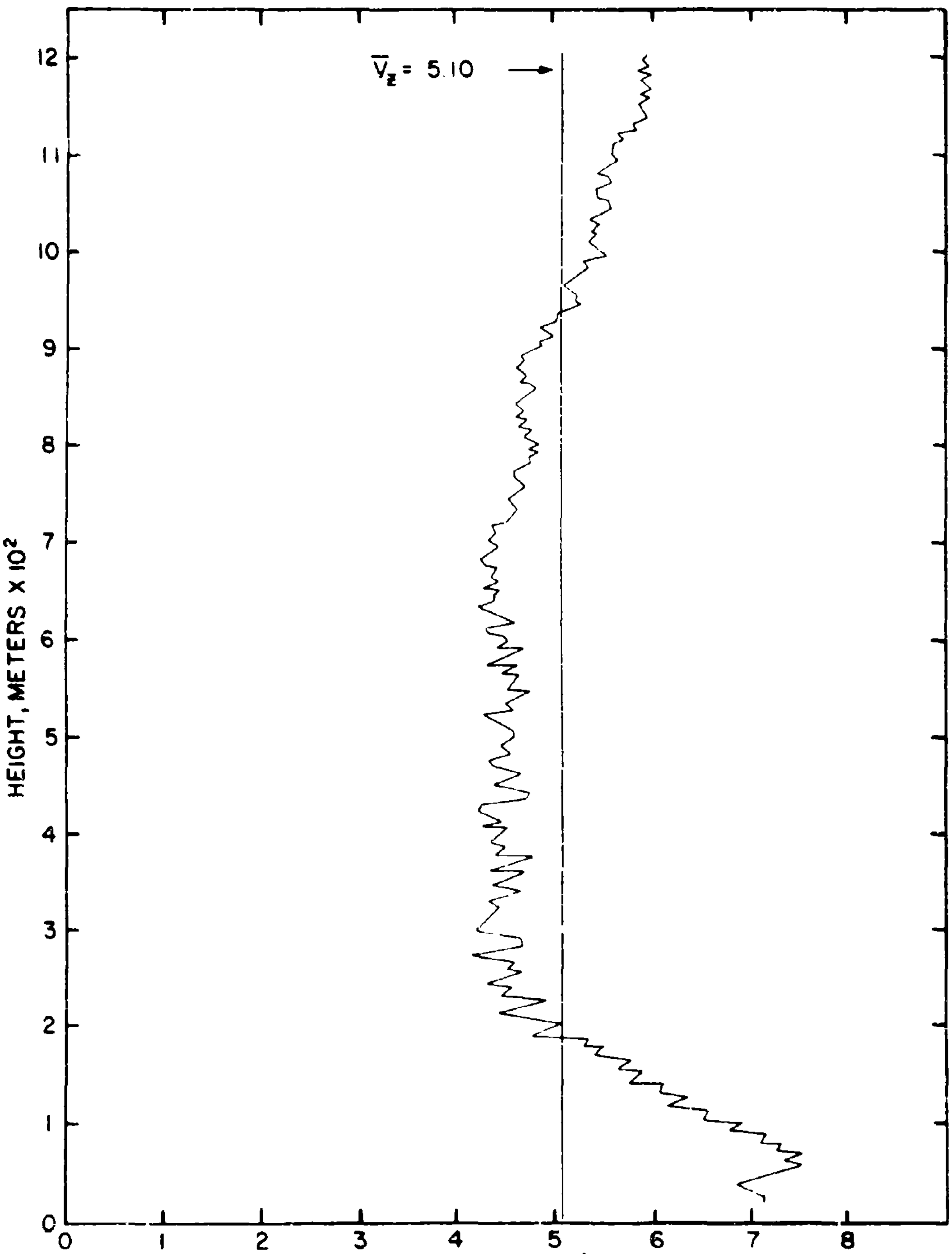

FIG. 1B. VARIATION OF THE ASCENT RATE OF THE JIMSPHERE BALLOON RELEASED AT 1115 MST 5AUG1968.

ascent rate (5.16 m $second^{-1}$) for all the 2 m balloons released in a two-and-one-quarter-hour period. Figure 1B shows the variation of the ascent rate of the balloon released at 1115 MST, 5 August 1968 where the mean ascent rate is represented by the vertical solid line (5.10 m $second^{-1}$).

Figures 2 through 5 show the variation of $\bar{w}$ (by 100 m layers) with height during periods of different degrees of thermal stability. At the same time, reference should be made to Figure 6 in which temperature profiles are plotted from radiosonde observations taken in the same area.

Figure 2 shows $\bar{w}$ for the first two and the last two releases of a series of 20 Jimsphere runs spaced six minutes apart on 29 November 1966. As the instability increased in the lower layers, the magnitude of the mean vertical winds increased from approximately 10 - 25 cm sec^{-1} to 55 - 85 cm sec^{-1}. Similarly, in Figure 3 there is also a marked increase in vertical winds with an increase in instability during another series of 20 cinetheodolite/Jimsphere runs on 12 December 1966. Continuing this analogy, Figure 4 presents the vertical variation of the vertical wind for two cinetheodolite/Jimsphere runs an hour apart on 10 July 1967 and Figure 5 two runs an hour apart on 5 August 1968. Vertical wind components are stronger, and updraft and downdrafts are sustained through deeper layers with decreasing stability. Further variation of vertical wind with height and stability can be seen in Figure 7 where the absolute means $|\bar{w}|$ by 100 m layers for all the soundings made on a particular day are plotted.

For study of the behavior of the standard deviation of the vertical wind (σ_w) above the surface boundary layer, there are primarily the measurements by Smith (1961) from vanes mounted on tethered balloons and by Bunker (1956) by means of a slow aircraft. Figure 8 reproduces Smith's observed relation between the standard deviation of vertical angle, wind speed, and stability. The variation of σ_w (with stability) was objectively confirmed by associating with each point the stability deduced from observations of temperature gradient in the vertical, made as near as possible to the time of record. This study agrees in a general way with Figure 8, as can be seen in Figure 9, which was plotted from the cinetheodolite/Jimsphere data. The difference in the methods of arriving at a stability classification by Smith and in this paper must be pointed out. Smith obtained the overall lapse rate from the ground up to the vane, whereas in this study, the lapse rate was considered only for individual 100 m layers where $\bar{w}$, σ_w and the horizontal wind (u) were computed. In addition, Smith's measurements of $\bar{w}$, σ_w, and u are Eulerian or Lagrangian, but perhaps more nearly Lagrangian than Eulerian. Much of the data were collected in the winter with stable lapse rate and relatively light winds. This gave several points with the ratio

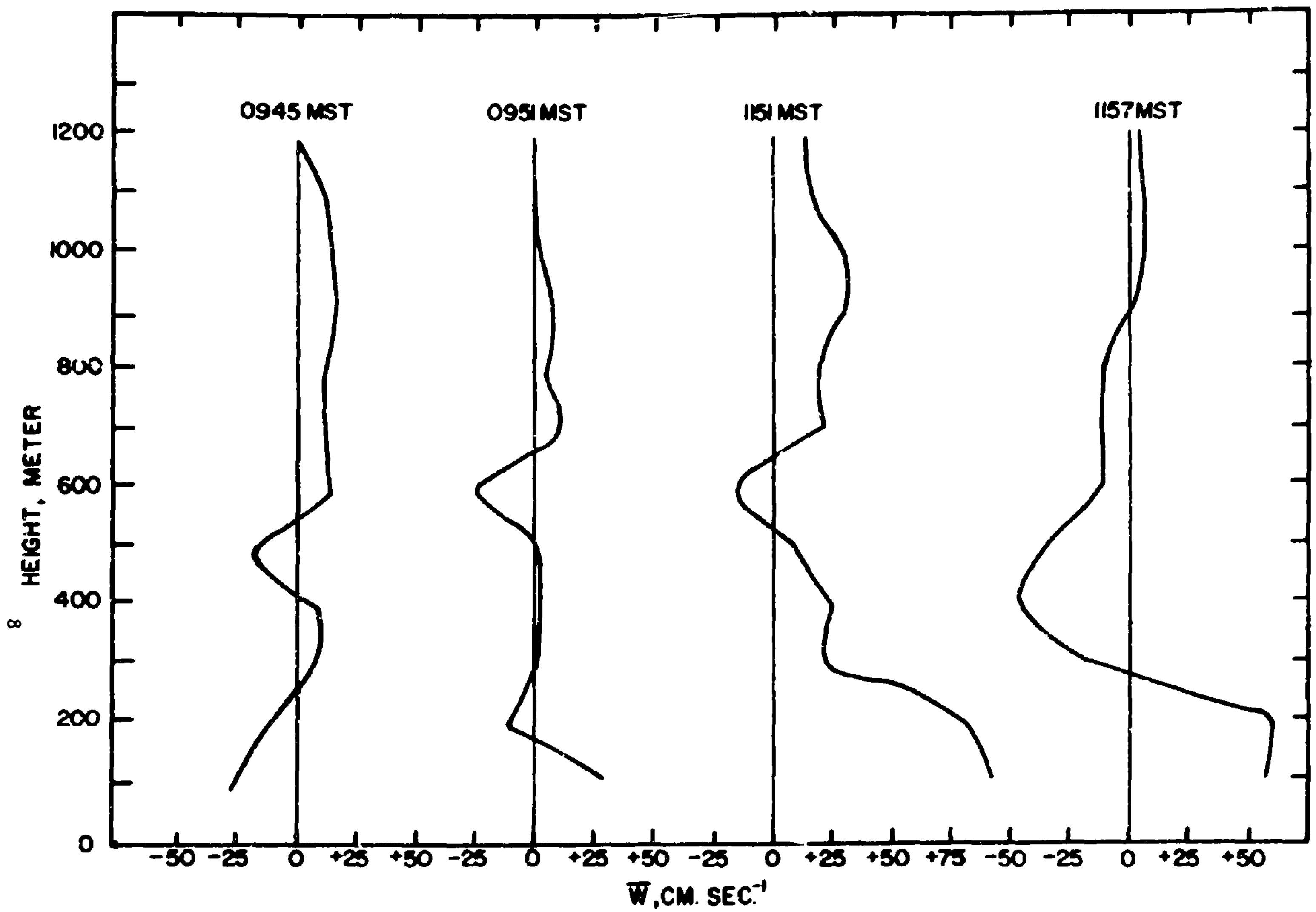

FIG. 2. ALGEBRAIC MEANS OF THE COMPUTED VERTICAL WIND FOR THE FIRST AND LAST TWO OBSERVATIONS FOR 29 NOV. 1966.

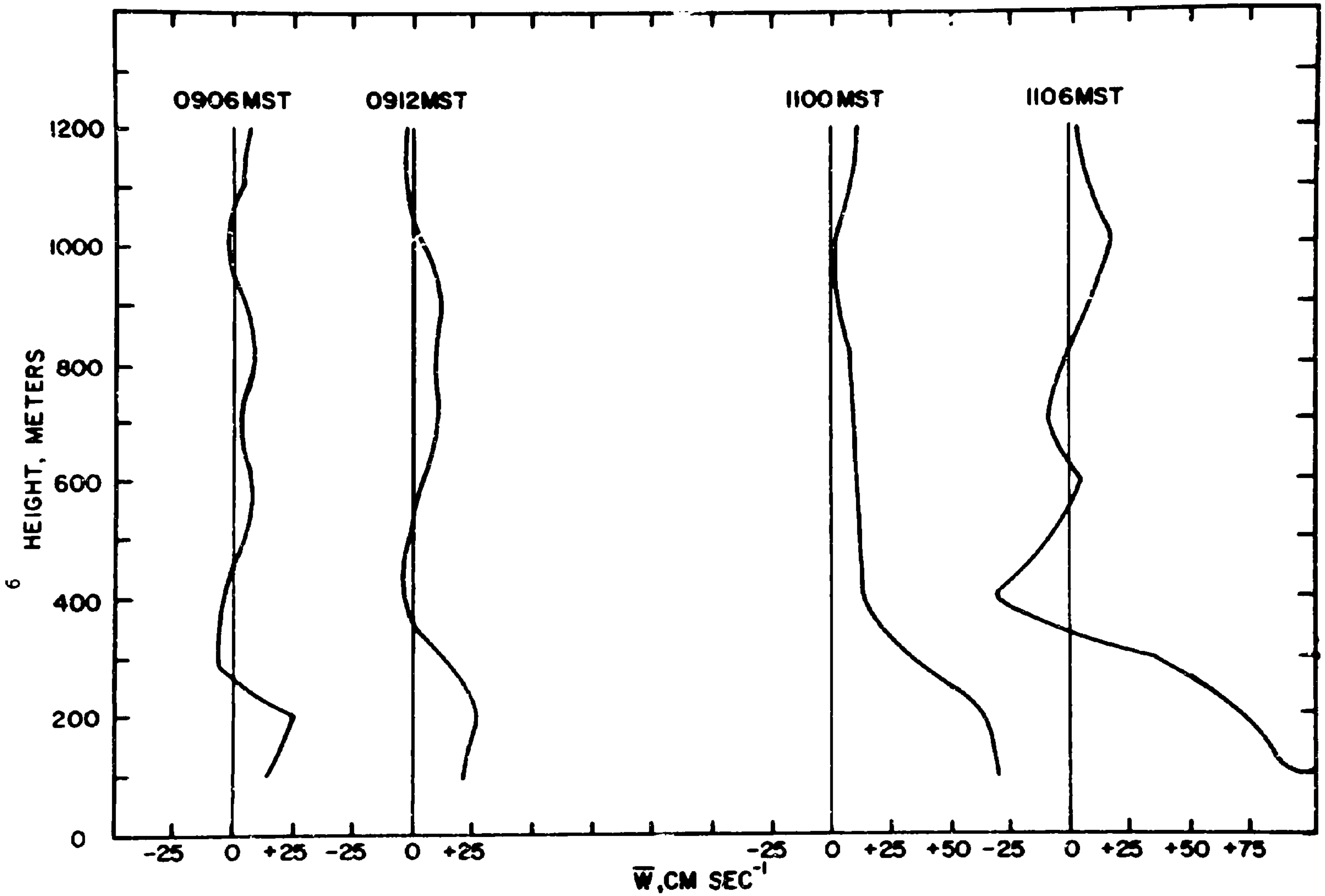

FIG. 3 ALGEBRAIC MEANS OF THE COMPUTED VERTICAL WIND FOR THE FIRST AND LAST TWO OBSERVATIONS FOR 12 DEC. 1966.

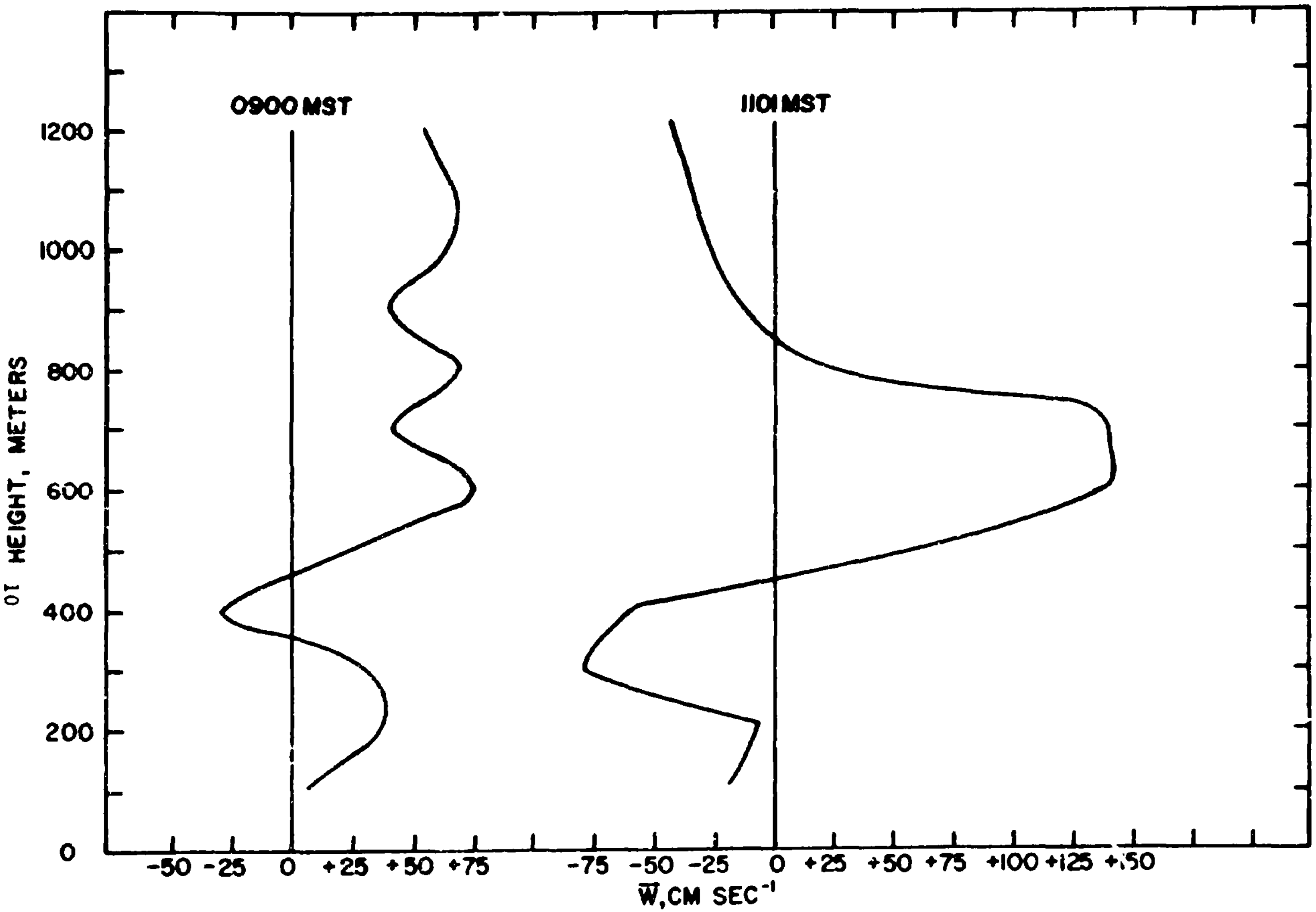

FIG. 4. ALGEBRAIC MEANS OF THE COMPUTED VERTICAL WIND FOR THE FIRST AND LAST TWO OBSERVATIONS FOR 10 JULY 1967.

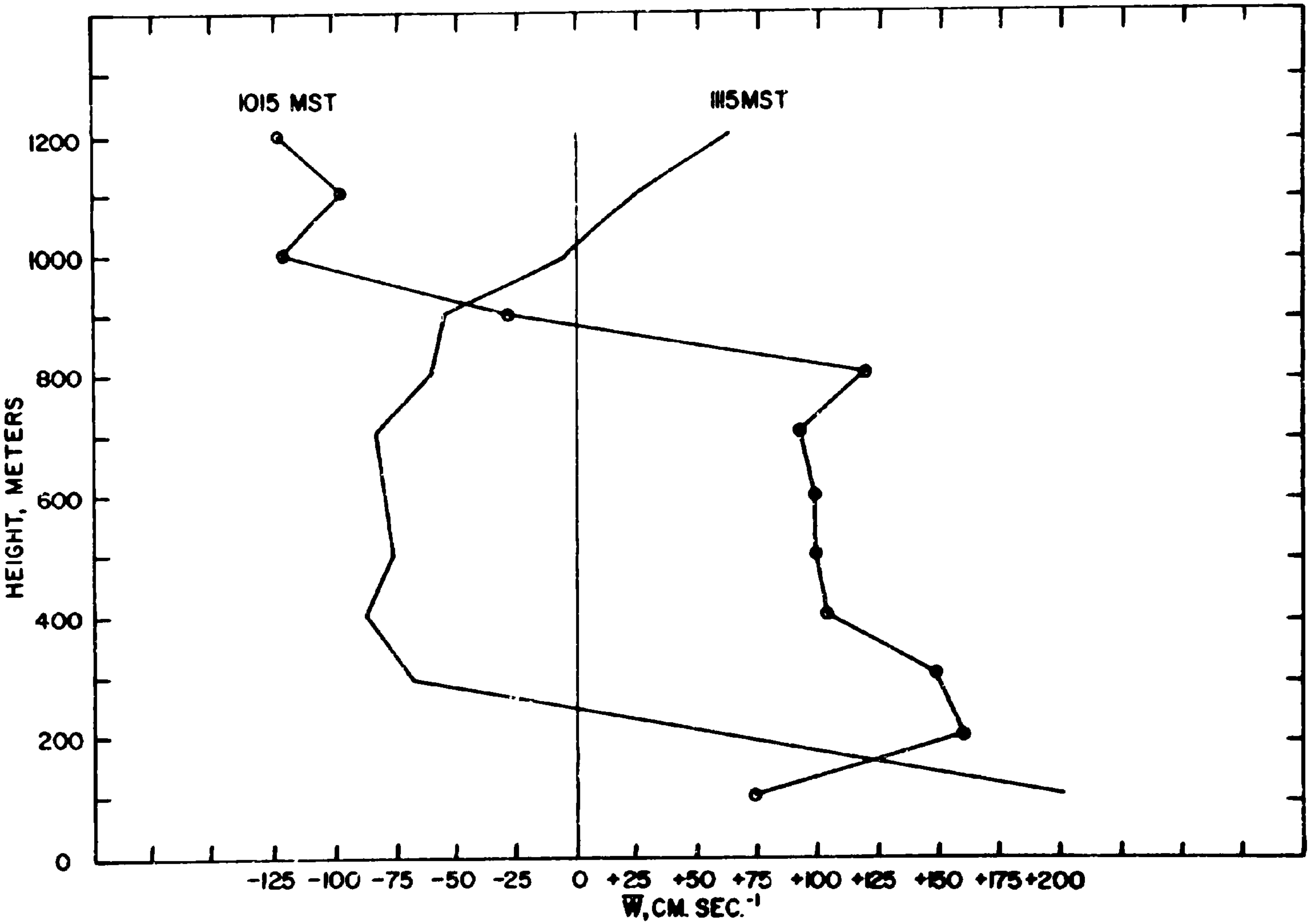

FIG. 5. ALGEBRAIC MEANS OF THE COMPUTED VERTICAL WIND FOR THE FIRST AND LAST OBSERVATION FOR 5 AUG. 1968

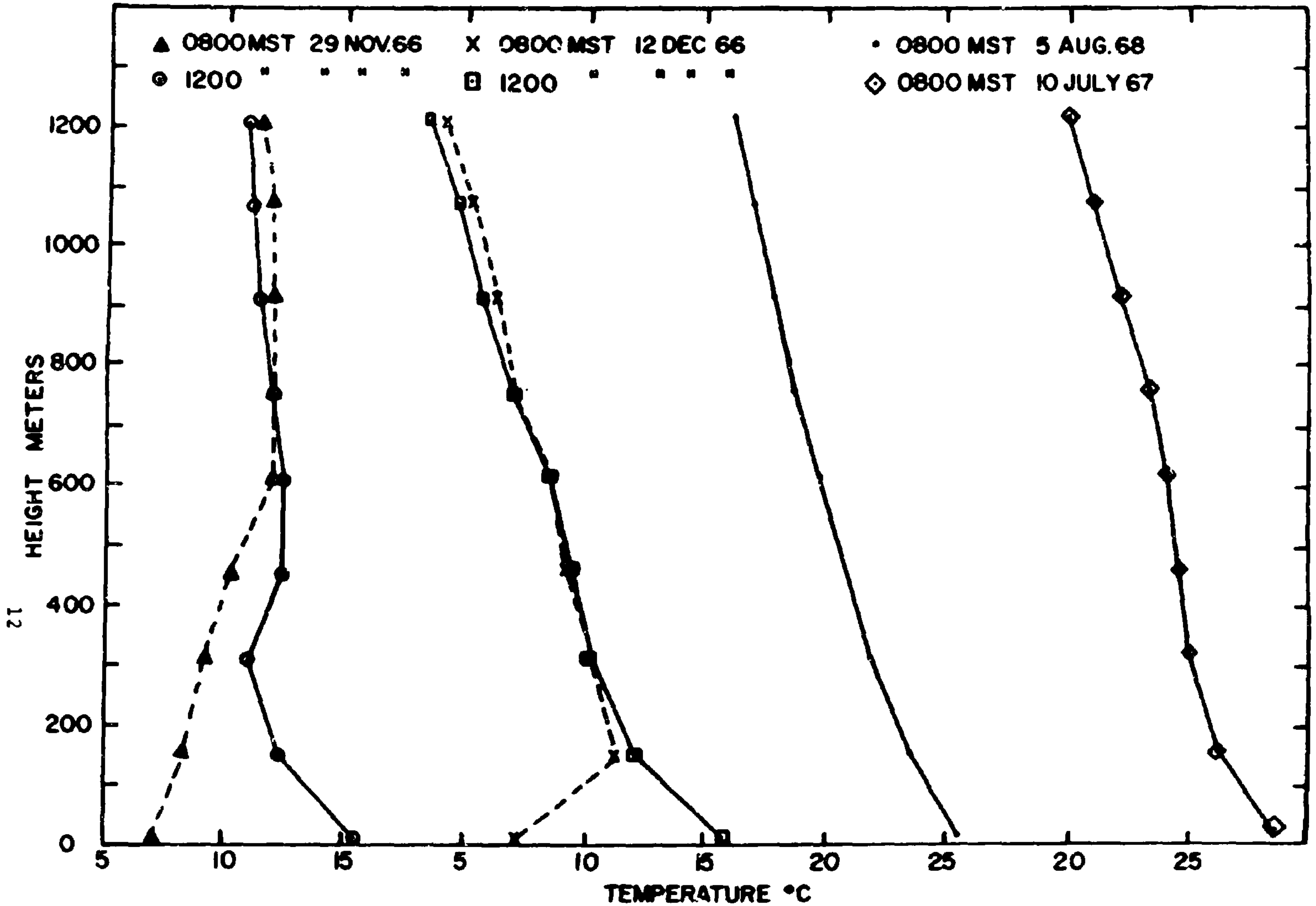

FIG. 6. TEMPERATURE PROFILES FOR 0800 AND 1200 MST ON 29 NOV. 1966 AND 12 DEC. 1966, AND FOR 0800 MST ON 10 JULY 1967 AND 5 AUG. 1968.

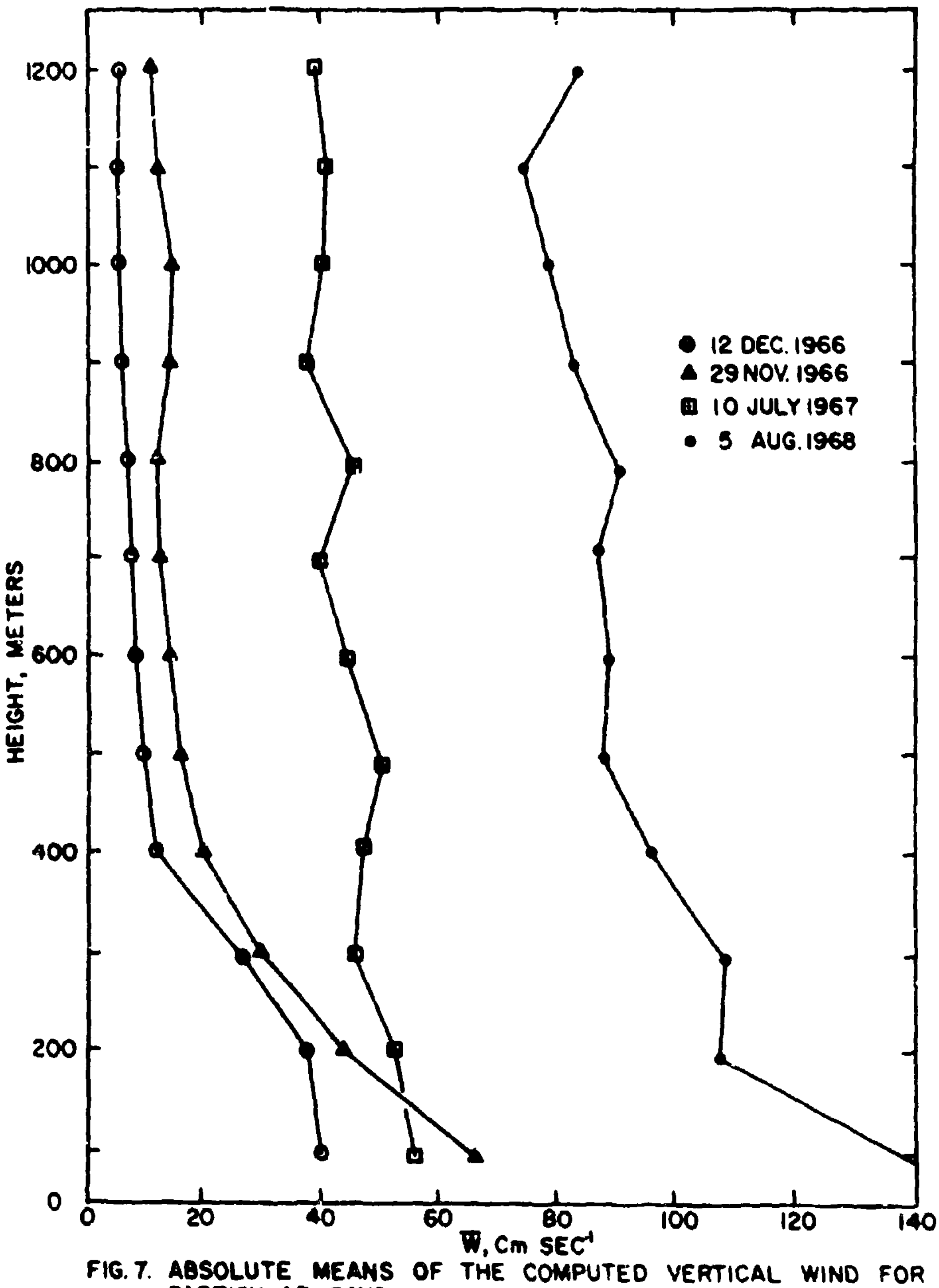

FIG. 7. ABSOLUTE MEANS OF THE COMPUTED VERTICAL WIND FOR PARTICULAR DAYS.

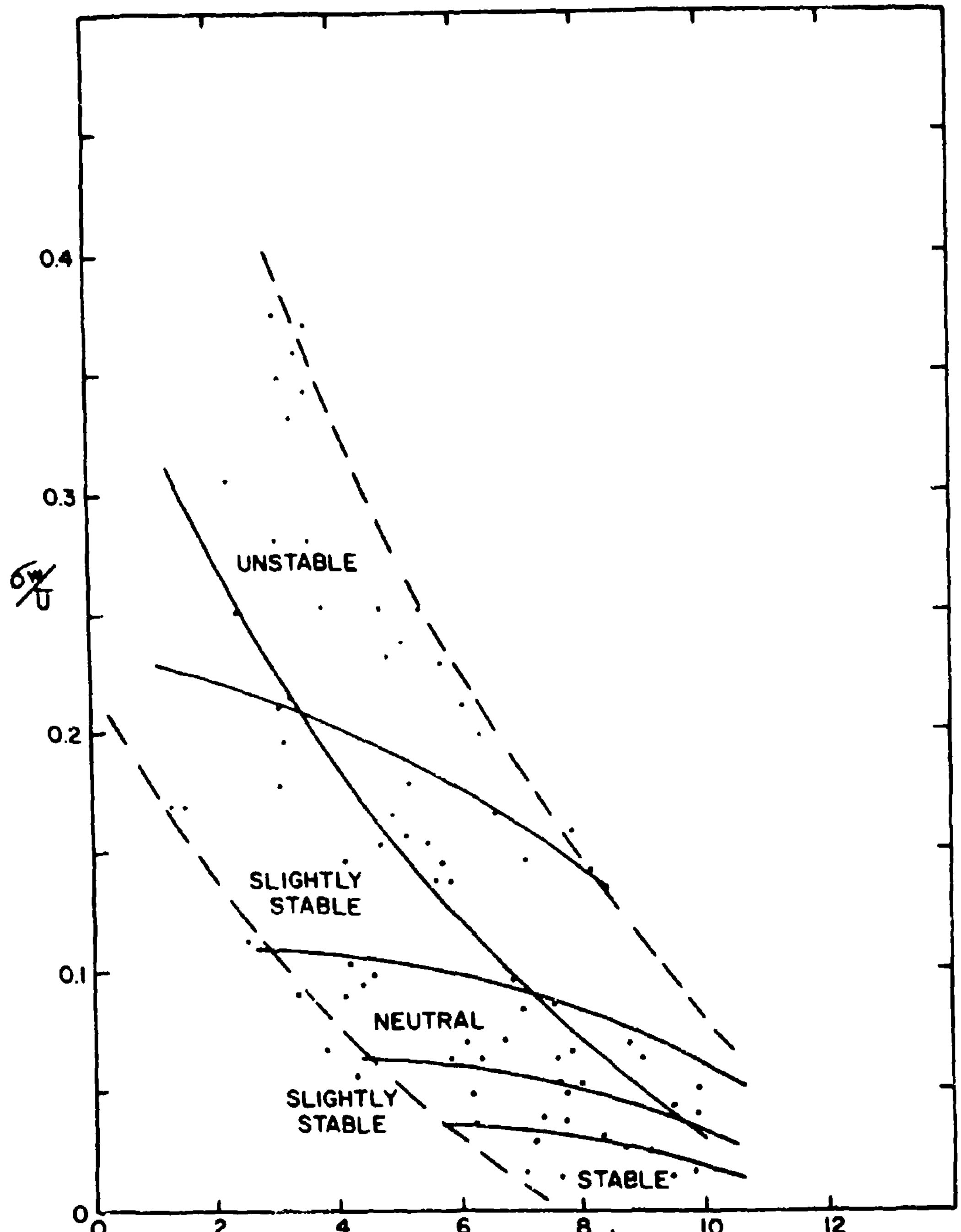

FIG. 8. THE RATIO OF σ_w TO $\bar{U}$ AS A FUNCTION $\bar{U}$ AND STABILITY BETWEEN 500 AND 5000 FEET AT CARDINGTON. (SMITH, 1961)

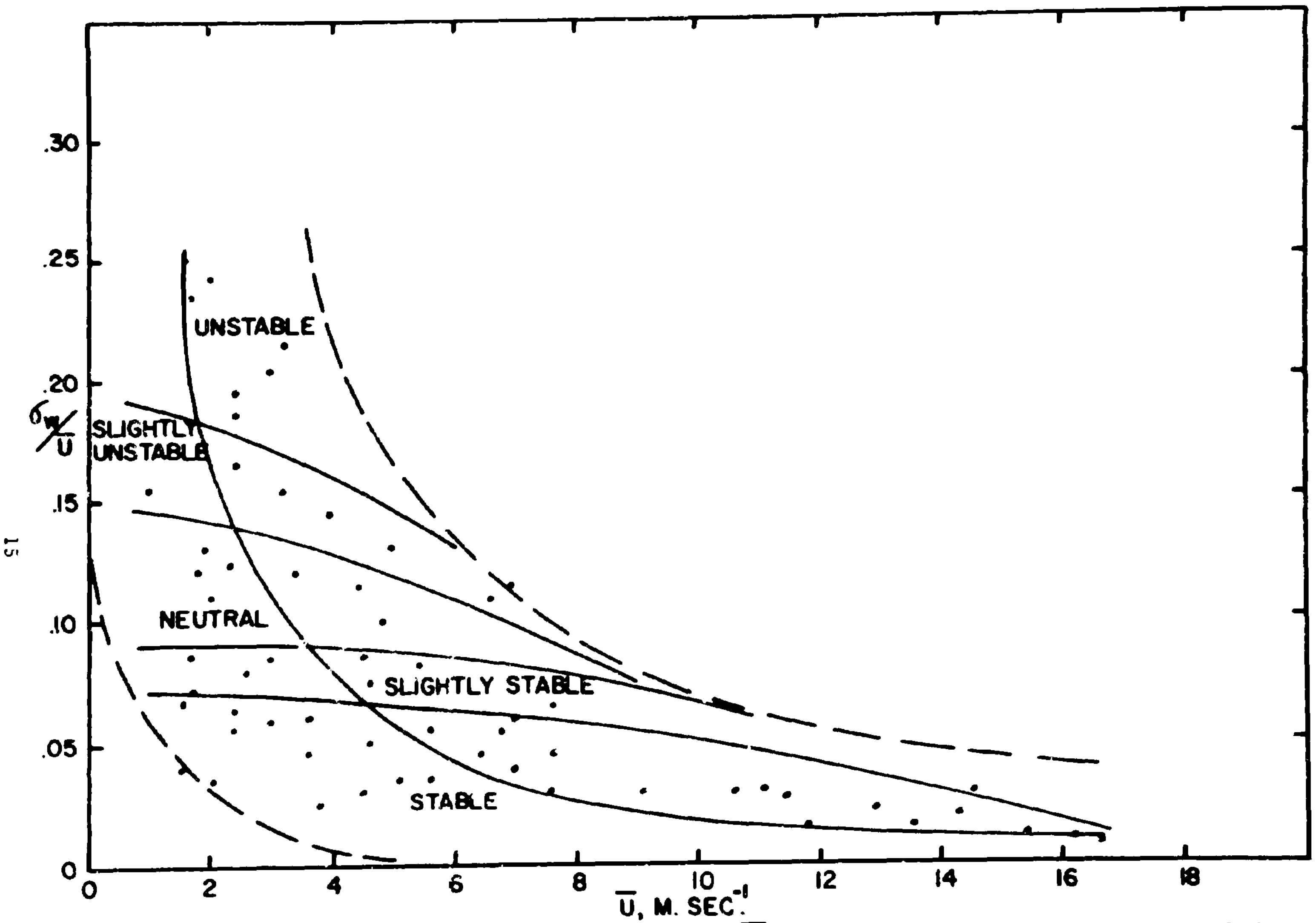

FIG. 9. THE RATIO OF σ_w TO $\overline{U}$ AS A FUNCTION OF $\overline{U}$ AND STABILITY BETWEEN THE SURFACE AND 1200 METERS AT WSMR.

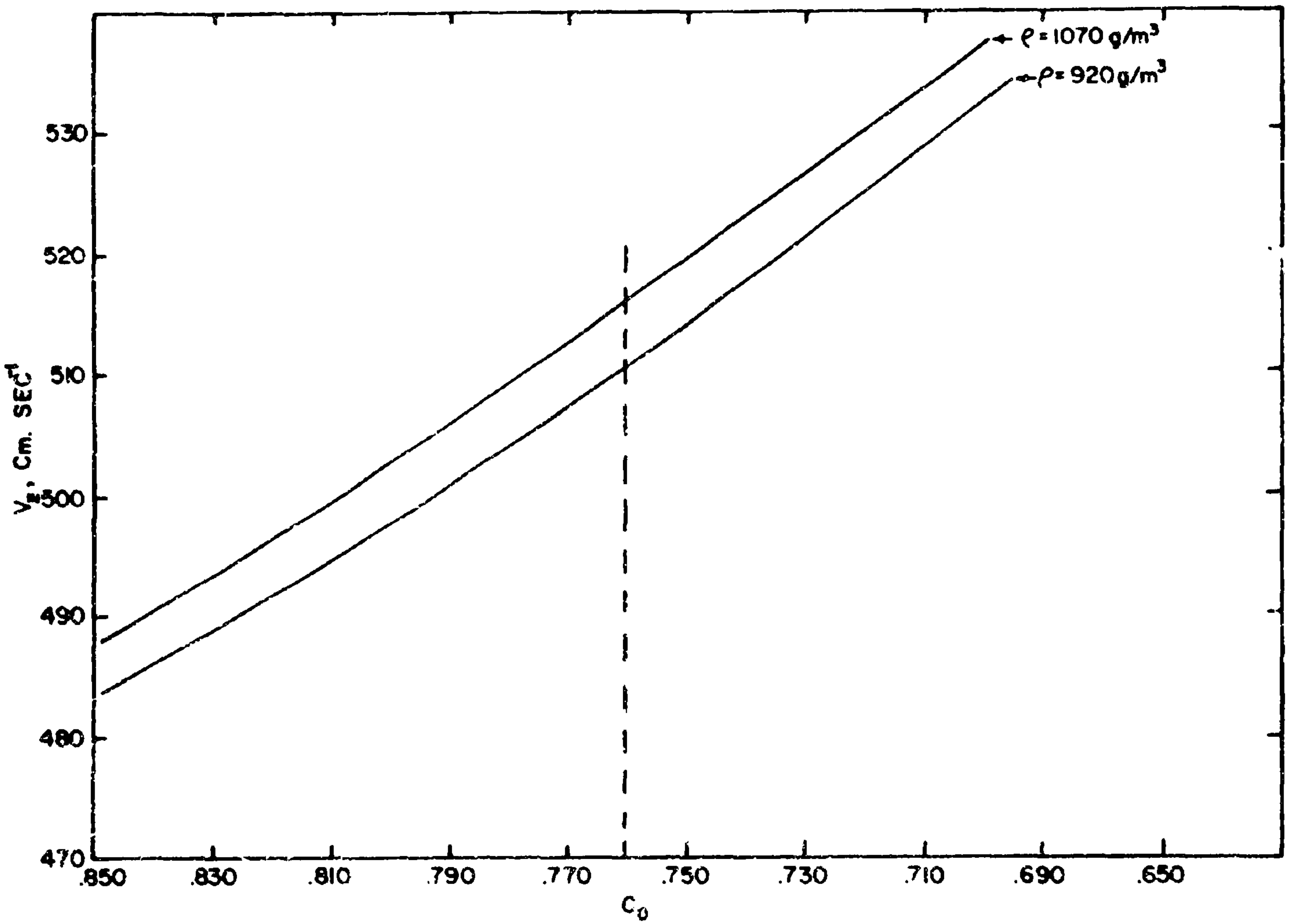

FIG. 10. BALLOON ASCENT RATE VERSUS THE CONSTANT CD IN THE RELATIONSHIP $V_E = \left[\frac{1}{CD}\left(2.26 \times 10^5 - \frac{25.5}{\rho}\right)\right]^{1/2}$ FOR A DENSITY OF 920 AND 1070 g/m^3.

$\sigma_w/\bar{u}$ less than .10 and wind speed less than 8 mps. However, there were several situations with stable lapse rate and horizontal winds up to nearly 17 mps.

CONCLUSIONS

It appears that vertical wind components can be estimated within the first few hundred meters above the surface by utilizing the cinetheodolite/Jimsphere system with suitable smoothing techniques. The magnitude of these vertical wind components is apparently controlled to a large degree by the thermal stability of the atmosphere. In unstable air the vertical winds are much stronger (55 - 100 cm sec^{-1}) and the sign (up or down) persists through much deeper layers than when the air is stable. Under stable conditions, vertical wind components are of the order of 10 - 25 cm sec^{-1}. This agrees well with accepted theory since convective turbulence has a much longer wavelength than mechanical turbulence. The variability of the vertical wind is a function of stability to some degree, as well as of the horizontal wind speed.

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APPENDIX A

Frequency Response for the 11-Point Second-Degree Polynomial Smoothing

This smoothing is accomplished by fitting a second-degree polynomial to 11 consecutive points by least squares and evaluating the polynomial at the midpoint. This process is continued by "slipping" one point until all the data are smoothed (except the first and last five points).

The normal equations for the least squares fit are:

$$\Sigma x = a\Sigma t^2 + b\Sigma t + nc$$

$$\Sigma tx = a\Sigma t^3 + b\Sigma t^2 + c\Sigma t$$

$$\Sigma t^2 x = a\Sigma t^4 + b\Sigma t^3 + c\Sigma t^2$$

The computations are considerably simplified by continually "slipping" the t-axis so that the midpoint of the 11 points is defined to be $t = 0$. Observe that $\Sigma t^n = 0$ for n odd. Also the parabola

$$X_s = at^2 + bt + c$$

degenerates to $X_s = c$ since the smoothed value is at the midpoint ($t = 0$).

The normal equations become

$$\Sigma x = a\Sigma t^2 \qquad + nc$$

$$\Sigma tx = \qquad b\Sigma t^2$$

$$\Sigma t^2 x = a\Sigma t^4 \qquad + c\Sigma t^2$$

Hence

$$c = \frac{\Sigma t^2 \Sigma t^2 x - \Sigma t^4 \Sigma x}{(\Sigma t^2)^2 - n\Sigma t^4}$$

which can be written as

$$c = \frac{\Sigma(t^2 \Sigma t^2 - \Sigma t^4)X}{(\Sigma t^2)^2 - n\Sigma t^4}$$

In terms of filter weights this becomes, since $\Delta t = 1$,

$$X_s = \frac{\sum(i^2\Sigma i^2 - \Sigma i^4)X_i}{(\Sigma t^2)^2 - n\Sigma t^4} = \sum W_i X_i$$

where X_s is the smoothed value and each of the summations is $\sum_{i=-5}^{5}$.

Performing the arithmetic gives (observe $W_{-i} = W_i$)

$W_o = 1958/9438$ $\quad$ $W_1 = 1848/9438$ $\quad$ $W_2 = 1518/9438.$

$W_3 = 968/9438$ $\quad$ $W_4 = 198/9438$ $\quad$ $W_5 = 792/9438.$

The filter response is, since $\Delta t = 1$,

$$R(f) = W_o + 2\sum_{i=1}^{5} W_i \cos 2\pi if$$

$$= \frac{1}{9438}[1958 + 2\{1848 \cos 2\pi f + 1518 \cos 4\pi f + 968 \cos (6\pi f)$$

$$+ 198 \cos 8\pi f - 792 \cos 10\pi f\}].$$

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13. ABSTRACT

Vertical wind components were computed up to 1.2 km from 37 wintertime and 10 summertime balloon observations between 0900 and 1200 local time utilizing the accurate and high resolution Cinetheodolite/Jimsphere system. The mean ascent rate of the Jimsphere was computed from all observations taken on a particular day. The ascent rate was found to be 5.16 m/sec^{-1} for the winter and 5.10 m/sec^{-1} for the summer months. The individual variations of a given observation from the mean ascent rate were assumed to be the vertical component. Variations in balloon ascent caused by variation in drag, anomalous variation in atmospheric density, balloon response to the wind, and aerodynamically induced motions are discussed. Vertical wind components ranged from 10-25 cm sec^{-1} in a stable atmosphere and 55-100 cm sec^{-1} under unstable conditions depending on wind speed.

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